The role of the biomedical physicist in the education of the healthcare professions: An EFOMP project


Abstract The role of the biomedical physicist in the education of the healthcare professions has not yet been studied in a systematic manner. This article presents the first results of an EFOMP project aimed at researching and developing this important component of the role of the biomedical physicist. A background to the study expands on the reasons that led to the need for the project. This is followed by an extensive review of the published literature regarding the role. This focuses mainly on the teaching contributions within programmes for physicians, diagnostic radiographers, radiation therapists, and the postgraduate medical specializations of radiology, radiotherapy, interventional radiology and cardiology. Finally
Definitions

Biomedical physics

The use of physics concepts, theories and methods for the greater understanding and development of clinical practice and experimental medicine. This is a wider definition than clinical medical physics and would include physics based aspects of life science research which would have a future impact on clinical practice (e.g., microscopy, nanodevices, spectrometry). At a more mundane level the term is also used in this paper to allow for the fact that most departments in Europe within Medical/Health Science Faculties are called either ‘medical physics’ or ‘biophysics’ or some combination of both terms. Most basic science departments within faculties of medicine/health science are now being grouped under the generic term ‘biomedical sciences’. Many biomedical physics departments today are of necessity multi-disciplinary and include physicists, engineers, mathematicians and sometimes chemists and physicians. By ‘biomedical physics department’ we include any entity whether in a Faculty of Medicine/Health Science or otherwise (e.g., Department of Physics in a Faculty of Science, hospital based medical physics department) providing such services.

Curriculum development model

A strategy by which curriculum development can be approached comprehensively and systematically.

Faculty of Medicine/Health Science

A university-based organizational entity which includes the education of healthcare professionals as one of the principal components of its mission statement.

Healthcare professions

The term ‘healthcare professions’ includes physicians, dental surgeons and the paramedical professions. The latter are defined as ‘All types of professions related to medicine, e.g., personnel in the fields of nursing, midwifery, sanitation, dental hygiene, pharmacy, physiotherapy, laboratory medicine, therapeutic exercise, radiography’ (European Observatory on Health Systems and Policies, http://www.euro.who.int/observatory/Glossary/TopPage?phrase=P).

Higher education

It refers to institutions which provide programmes at Bachelor or higher level as defined by the European Higher Education Area (http://www.eua.be/index.php?id=65).

Role development model

Role development is an umbrella term for the making, elaboration, redefinition, modification and expansion of a role; a role development model is a strategic plan that would take a role from its present state to a desired enhanced future state.

Introduction

The policy statements describing the role of the medical physicist published by the EFOMP and most national medical physics organizations include the obligation of providing a constructive contribution to the education of healthcare professionals (HCP). As a result, biomedical physics (BMP) departments provide educational services in most Faculties of Medicine/Health Science (FMHS) in Europe. In 2005, the EFOMP Council took the decision to set up a Special Interest Group (SIG) to develop the role of the biomedical physics educator in such faculties and to work with other healthcare professional groups to produce updated European curricula for them. This article presents the first contribution by the group providing a background to the project, an extensive review of the published literature regarding the role and a list of the specific research objectives that need to be addressed. The effort of the group would provide a base for the future well-being of the role, its relevance to modern healthcare professional education and provide input for future EFOMP policy documents regarding this important component of the role of the medical physicist.

Background to the study

A well-developed body of literature exists regarding the education of the HCP, however, there are very few articles regarding the BMP component. A scrutiny of the HCP educational literature provides relatively few references. In addition, a cursory survey of HCP programme web pages in Europe indicates that current BMP curricular content even for a single profession such as that of a physician varies tremendously ranging from general physics to physical biochemistry, biomolecular and cellular biophysics, physiological physics, the effects of physical agents on the human organism and medical devices. From the personal experience of the members of the group there are various causes for this variability. Remits presented to BMP educators by HCP programme leaders are sometimes quite vague as the latter are often unsure on what the learning requirements of their students are, above the fact that their students ‘need some physics’. Choice of curriculum content is often subjective with BMP educators simply choosing learning objectives based on those areas of their
expertise that in their opinion are most relevant to the particular HCP. Research-based curriculum development and international networking on the issues are sorely lacking. This ad hoc approach to curriculum development in many cases leads to learning objectives that are far removed from the everyday practicalities in the exercise of the HCP, hence leading to a low level of satisfaction and motivation on the part of the students. There are also indications that the BMP academic is not perceived by the various HCP to have a clear, valuable and easily identifiable role with respect to the education of their students — an issue which if not addressed with urgency by the profession could lead to a reduction of curriculum time devoted to BMP in the various HCP curricula and this at a time when the number and sophistication of medical devices are on the increase and the physics knowledge of students entering these professions is on the decrease. At the same time, the gradual construction of the European Higher Education Area (often referred to as the 'Bologna' process) is encouraging institutions involved in higher education to take a critical look at their curricula and ensure that the latter are more in agreement with the present and future learning needs of the professions. The Tuning Educational Structures in Europe initiative (http://ec.europa.eu/education/policies/educ/tuning/tuning_en.html) is promoting the use of practice-oriented curricula in which programme end-points are expressed in terms of the competences that students should acquire by the time they finish their studies. BMP educators cannot play a significant role in this process unless they have a clear updated role mission statement and are in possession of research-based role and curriculum development models to guide their activity.

Literature review

This literature review starts with a short historical overview of the development of the relationship between physics and healthcare as a backdrop in helping the reader understand the present role of the BMP educator and the possibilities for its future development. Texts with the term 'Medical Physics' in the title were published as early as 1856 and 1891 [1,2], however, the influence of physics in medicine registered a dramatic leap only after the discovery of X-rays by Roentgen (1895) and radioactivity by Becquerel (1896). Developments in the first years were mostly in radiodagnosis whilst those in radiotherapy started in 1910 [3]. From then onwards, the involvement of physicists in medicine spread rapidly to other areas of healthcare. The first comprehensive medical physics text was the three volume 'Medical Physics' by Glasser (1944–1960) which included 23 domains of medicine where close collaboration between physicists and medical specialists was required [4]. Today medical physics and engineering play a part in most areas of medicine. In an article describing the development of radiiodine studies of the thyroid it was remarked that “the cooperation between physicists and physicians that made their accomplishments possible stands as a model example for interdisciplinary collaboration” [5]. Yet despite this rich heritage of interdisciplinary collaboration between BMP practitioners on one side and the HCP on the other, and despite the fact that most professional BMP organizations, e.g., EFOMP do speak of the importance of the educator role with regard to BMP education within their policy documents [6–8] there is very little published evidence regarding such activities. The scant literature indicates that the collaboration experienced in the clinical and research environments did not transfer satisfactorily to the educational milieu. The few articles that do exist are restricted to undergraduate programmes for physicians (content mostly concerns diagnostic radiology, basic biomolecular science and physiological physics), diagnostic radiographers and radiation therapists (alternatively known as radiological technologists or radiological assistants), and the postgraduate medical specializations of radiology, radiotherapy and interventional radiology and cardiology — in other words the scope of the role has been mostly limited to the traditional areas of medical physics and has not been extended to other areas of BMP involvement in healthcare [9–45]. The literature review draws mainly on information from Western Europe because this is where the majority of published articles originate. However, as the work develops we will also be reporting the situation in Eastern Europe.

BMP teaching in programmes for physicians

There are very few articles regarding the BMP component in medical curricula even though BMP educators provide teaching in many medical programmes (particularly in Europe, a notable exception being the UK). The few papers that exist send contradictory signals regarding the effectiveness of teaching. The only work that has been described in detail is that of J. K. Robertson, Professor of physics teaching at the Queen’s University Faculty of Medicine in Canada in the years 1909–1951 [9,10]. The pedagogical approach of this early BMP educator is, however, unique in many ways and will be described in detail as it demonstrates the remarkable vision exhibited by some early BMP educators. Robertson started teaching medical students in 1909 at a time when the physics component in the medical curriculum was minimal. The number of lectures was two per week for a single term and concerned general physics. He considered this inadequate and instituted a course entitled ‘X-Rays and the Physics of Electro-Therapeutics’ as an option for final-year medical students (at the time radiology was not considered as a postgraduate medical specialty but was practiced by all physicians). The main objective of the unit was to ensure that future physicians would be able to understand the functioning of radiation based medical devices and hence be able to use them more effectively and safely. Another objective of the study unit was to ensure that they would be able to make informed decisions regarding the purchase and use of these devices. The course was quite comprehensive and also included radiation protection and a comparison of the features of the various devices available at the time. However, this course was not a success. The reasons given by him were that students who had learned their physics in the first year course had forgotten everything by the final year and that they assumed that this final-year course would be similar to the general first year course. As a result they preferred to
attended classes in areas which they perceived would be more directly relevant to their clinical practice. He solved the problem by convincing the faculty to move the final-year course to the second year of the programme and transformed this second year course into a combined electromagnetism and modern physics plus ‘X-Rays and the Physics of Electro-Therapeutics’ course, in effect combining scientific principles with clinical practical application in a single unit. His stated aim was to make physics as attractive as the clinical disciplines by showing its direct relevance to medicine. He stressed the applications of physics as opposed to general physics principles. This second year course combining pure and clinically applied physics in one unit “challenged the linear, rigidly structured medical curriculum of the day, with its strict separation of basic and applied science” [10] and was considered by Robertson himself as an experiment in medical education. As Hayter noted “Robertson’s success in this endeavour was based largely on two factors: his sympathetic understanding of the needs of medical students and his innovative combination of basic and applied science in one course — factors that are as important to medical teaching today as they were 50 years ago”. Robertson had the following advice for fellow physics educators: “Indeed, the physicist who teaches medical students should recognize that the mental approach to a scientific subject by those whose primary interest is medicine is not the same as that of the physicist and he should govern himself accordingly. Without sacrificing the quantitative aspect he should have a sympathetic understanding of a different type of mind” [9].

However, it seems that this initial brilliant flash of educational initiative was not followed up by the international BMP community (or at least not reported in the international scientific literature). Moreover, there are indications that the absence of systematic research and publication has in the past resulted in unsatisfactory learning outcomes with an unacceptably high theory—practice gap. In 1996, a retrospective evaluation of the medical curriculum by final-year students was carried out at the Hannover Medical School [11]. Students were asked to express their opinion on the relevance of the various subjects in their medical training. Physics was considered to be the least relevant of all the subjects with a ‘necessary subject rating’ of only 18% compared with 48% for chemistry and 54% for biology. The data were considered representative as the response rate was over 90% and the cohort large (n = 323). Comparable results were obtained in a second study by the same authors with physicians at the end of their specialization periods [12]. Although curriculum evaluations by students are influenced by the local educational environment such negative results do indicate problems which need to be identified and addressed.

In 2001 an interesting attempt to introduce problem-based-learning based BMP teaching to medical students was reported and showed some evidence of increased interest in curriculum development. First year medical undergraduates were separated into two groups, the first being taught in the traditional manner and the second using problem-based-methods by a team of physicists, a biochemist and three medical doctors. There was no significant difference in assessment scores between the two groups at the end of the course, however, the problem-based-learning group was more satisfied with the course. The paper is interesting as it is the only one reporting such activities, however, unfortunately there is no indication what the actual cases were and how the physics was integrated within the clinical cases [13]. In 2005, the EFOMP published a radiation protection syllabus for medical undergraduates in response to a call by the European Commission (Directive, 97/43/Euratom), that “member states shall encourage the introduction of a course on radiation protection in the basic curriculum of medical and dental schools” [14]. The syllabus is not competence-based and in this respect needs to be updated. Some authors have appealed for a widening of content and for the inclusion of such topics as the principles of biosignal measurement and processing [15]. Again, in 2005, a survey targeting the BMP component of European undergraduate medical curricula produced some highly relevant results [16]. The authors conducted a preliminary exploratory survey via medical faculty web pages across Europe and a sample of universities was chosen (total 48 medical faculties from all member states of the expanded EU). This was followed by in-depth studies of the BMP component of the curricula at the selected universities. Data were collected from websites, curricular documents, recommended textbooks and via direct correspondence with the respective faculties. The results of the study indicated a wide variation in extent, content and method of delivery. The main thematic findings included the following:

- In general a compulsory physics contribution is included in the pre-clinical stage, whilst further optional units are offered in the clinical years.
- There is wide variation in the compulsory pre-clinical curriculum time devoted for physics, ranging from 90 h (e.g., CZ) to zero (e.g., UK). This wide variation in the number of hours has recently been confirmed in an independent study [17].
- In some countries the BMP component is a national legal requirement (e.g., FR, DE) whilst in others it is discretionary (e.g., PT).
- There is a wide variation in curriculum content from medical devices to physiological physics, biomolecular and cellular biophysics, imaging physics, systems analysis, radiation physics, radiation protection, and general non-applied physics. In some countries law specifies content in a detailed manner (e.g., FR) whilst in others it only offers general direction (e.g., DE).
- Content delivery is still mainly presentation based. Interestingly, in some countries physics practicals are mandated by law (e.g., DE). The authors reported that in some universities they found excellent practicals designed specifically for the needs of medical students as opposed to mere modified versions of mainstream physics practicals (e.g., CZ, NL).
- There is a lack of systematic, research-based curriculum development. Most content selection is still opinion-based. This often results in an insufficient contribution to the outcome learning competences of medical programmes.
Most departments have not yet reacted sufficiently to modern developments in higher education in general and medical education in particular, such as, integrated curricula, problem-based-learning, and competence-based curricula.

In a subsequent paper, the same authors developed an initial research-based BMP competence inventory for undergraduate medical education in Europe. The authors derived the suggested inventory from a functionalist oriented analysis of EU legislation, recommendations by European national medical councils, educational benchmark statements by HE quality assurance agencies, and other documents relevant to standards in medical practice and undergraduate medical education such as the General Medical Council (UK) document Tomorrow’s Doctors, the Bundesministerium fur Gesundheit (DE) Approbationsordnung fur Arzte, and the Disciplinary Board of Medical Sciences of the Association of Universities in the Netherlands Blueprint 2001: Training of Doctors In The Netherlands. Functionalism emphasizes that curriculum content in healthcare professional education should be largely determined by the present role and envisaged future role developments of that particular profession within the healthcare system. Competences expected of a medical graduate that included subsumed BMP facets were identified and underpinning physics elements-of-competence singled out. A structured competence inventory was designed to serve as a practical curriculum development tool [18]. The inventory is a good initial step forward, however, the SIG feels that further elaboration and development is necessary.

BMP teaching in courses for diagnostic radiographers and radiation therapists

Physics has been included in the curriculum for diagnostic radiographers since the beginning of formal radiography education. In the UK, an article published in the journal Radiography in 1963 speaks of “an estimation of the necessity for physics in the training of the radiographer” [19]. This led to a symposium on the subject [20] and finally a basic syllabus [21]. However, no further updated work was published in the literature and though most radiographer’s associations and undergraduate schools of Radiography did publish locally developed physics syllabi under such diverse names as ‘radiation physics’, ‘principles of radiation science’, ‘imaging equipment’, ‘imaging instrumentation’, ‘radiation protection’ and others [22], there was no evidence of a systematic and studied approach. The College of Radiographers (UK), did include sections on ‘physical sciences’ and ‘technology’ in its curriculum framework for radiography, however, the document was very broad so further specification was required to produce statements of learning outcome competences that would be directly usable in the educational environment [23]. The first research-based, comprehensive inventory of BMP elements-of-competence for diagnostic radiography education in Europe was published in 2006 [24]. The authors brought together research articles in the English literature and published documentation pertinent to diagnostic radiography education, professional competence and role development and subjected these to a rigorous analysis of content from a functional and competence analysis perspective. Translations of radiography curricula from across Europe and relevant EU legislation provided a pan-European perspective. Broad Subject Specific Competences for Diagnostic Radiography that included major BMP components were singled out. These competences were in turn carefully deconstructed into specific elements-of-competence and an inventory consisting of those elements falling within the BMP domain was developed. Participants at a meeting of the Higher Education Network for Radiography in Europe (HENRE, www.henre.co.uk) evaluated a pilot version of the inventory. The inventory was subsequently further refined taking into consideration the suggestions offered by HENRE members. The inventory was designed to be a pragmatic tool for curriculum development across the entire range of radiography education up to doctorate level. It is also important to note that with respect to the patient and occupational safety component of diagnostic radiography education, BMP have always been very much involved in European and international (ICRP, IAEA) initiatives targeted towards the development of educational resources for the radiation protection aspect of diagnostic exposures (e.g., MARTIR multimedia e-learning materials, Radiation Protection 116 Guidelines on Education and Training in radiation Protection for Medical Exposures [25,26]). Physicists are also presently involved in an ICRP group working on a document entitled ‘Radiation protection training for diagnostic and interventional procedures’ which is expected to be published during 2009 and which would be highly relevant to diagnostic radiography education (Vano E., personal communication, February 2008).

Therapeutic radiology is the main area in which physicists and other HCP have worked together in a concerted and systematic manner and on a European scale to produce curricula and educational materials for the three HCP involved, i.e., radiotherapists (alternatively known as ‘radiation oncologists’), medical physicists and radiation therapists (alternatively known as ‘therapeutic radiographers’). An extensive curriculum development programme has been carried out as part of the project ESQUIRE (Education, Science and Quality Assurance for Radiotherapy) which is run under the auspices of the European Society for Therapeutic Radiology and Oncology (ESTRO) and financed by the EC (Europe Against Cancer initiative). An important outcome of the project was a European core curriculum for radiation therapists. A revised more recent version of this curriculum has an improved BMP component under the headings of ‘physics’ and ‘equipment’ [27–29]. A weakness of the curriculum is that it is not outcome competence-based as required by the Bologna process but simply presents a list of syllabus topics.

BMP teaching in the postgraduate medical specializations of radiology, radiotherapy and interventional radiology and cardiology

Physics has always been a staple component of the curriculum of the postgraduate medical specializations of
radiology and radiotherapy albeit with mixed success [30–35]. In 1989, the Committee on Training of Radiologists of the American Association of Physicians in Medicine, published the results of a survey conducted among recently certified radiologists regarding their perceptions of the radiological physics training which they received during their radiology residencies [36]. The most important results of the survey for this study were that:

(a) Seventy-two percent of the respondents had a negative opinion of physics as presented in their programs at the time, however, the same percentage continued to attend physics training even after graduating and notwithstanding the fact that they were not obliged to do so for certification reasons! This clearly indicated that “radiologists actually do consider physics to be a worthwhile endeavour”.

(b) The respondents indicated that they would have liked to have “an emphasis on subjects that are directly relevant to everyday practice” as they felt that “although they acknowledged the need for an understanding of basic physics principles, they clearly perceived that theory had been overemphasised”. The respondents wanted a greater emphasis on those topics relevant to the production of quality images and means of reducing radiation doses to patients.

The results of the survey triggered a discussion unabated in some form or another ever since. The arguments presented in the debate will be reviewed in some detail as they often reveal interesting opinions regarding justification for inclusion of BMP content which are relevant to all HCP curricula, and also criteria for choice of content which are very relevant to this project. It has been argued that it is the superior knowledge that radiologists have of physics that gives them an advantage over other clinicians who attempt to read medical images, as the latter are “a combination of both anatomical and physical information” and that these “form an inseparable unit”. “It is the job of the radiologist to combine his knowledge of anatomy, disease, and image production in formulating an interpretation. If one of these elements is missing, the interpretation is at best incomplete, if not incorrect. This is what happens when a clinician who has a thorough knowledge of the specific anatomy and disease process attempts to interpret radiologic images without an understanding of image production”. The authors then provide several convincing examples of the misdiagnoses that can occur through an inadequate knowledge of the imaging physics [37]. Other authors have echoed similar sentiments: “radiologists may be able to use their equipment in a safer and more effective manner than would be possible without such knowledge” [38]. In a point—counterpoint discussion it was argued that owing to the pressures on radiologists’ learning time only physics knowledge that is derived from the clinical practice should be taught. This has the advantage of demonstrating directly the relevance of physics knowledge. The best educators of physics for radiologists and by extension all HCP are those who have both physics and clinical knowledge, as the physicist must “translate” the physics to the clinical situation. Other advantages of this approach are that the student is more likely to retain the material after graduation and that it “preserves the image of the physicist as possessing valuable and occult knowledge” so that when complex situations arise in their practice the radiologists would feel the “need to consult with their medical physics colleagues”. These arguments were countered by the argument that it is more important to use the time available to build firm broad conceptual foundations as there are physical concepts which though not relevant at the time of learning could become so at a later date in particular with the rapid expansion of technology. By way of example the author mentions the case of magnetic resonance imaging stating: “in the 70s who would have thought that nuclear spins would play any role in radiology” [39]. A more recent debate involved a discussion on whether the general rapid increase in the number of imaging techniques (including molecular imaging) implies that the physics taught to radiologists would need to be expanded and become more quantitative and mathematical in nature [40]. The arguments in favour of the proposition tended to be statements on the lines that more sophisticated technology requires more in-depth physics knowledge. Arguments against the proposition were based on the facts that there is simply no available curriculum time and that medical students do not tend to be mathematically inclined: “While a physicist is comfortable working with integrals and exponentials, these incite fear and anxiety in most residents. Unfortunately, there is insufficient time to teach the fundamentals of mathematics along with the essential physics”. Teaching “should be performed using qualitative nonmathematical methods that are both understandable and pragmatic. These methods require more preparation time by the medical physicist, but the end is improved comprehension”. It is the author’s view that it is much more important to provide future radiologists with the background knowledge necessary for them to be able to recognize those instances during their future careers when they would need to seek out assistance from physicists. It is the view of the SIG that, although, a more quantitative approach is of course not suitable for all learners it is highly desirable and it is up to the individual educators to show the way to those who do have the necessary aptitude.

Some recent experiences in the teaching of the practical aspects of radiation protection to interventional radiologists and cardiologists have been well received by the clinicians and some of the medical societies are directly involved in the training and certification process [41–44]. The experience of the IAEA in the radiation protection training of interventional cardiologists has been highly positive. A survey carried out at the end of recent courses showed acceptance for the length of the courses and suitability of the curricula. Ninety-two percent of the participants at a pilot course in Vienna and 96% at another in Singapore stated that the course length of two days was suitable. The curriculum was, by and large, satisfactory, with only very few participants perceiving it as being “slightly too technical”. There was almost unanimous opinion that such programmes should be conducted more often and in more countries, that papers on radiation protection be published in cardiology journals and that
radiation protection lectures should be included in cardiology conferences [41]. Similar courses are also being organized at local level in various states. The Spanish Society of Vascular and Interventional Radiology organizes training courses in radiation protection focusing on interventional radiology practice. A survey carried out at the end of a pilot training course lead to the results that a 20-h course length was considered appropriate by 95% of delegates whilst the global score indicating level of satisfaction with the course syllabus was 8.3 out of a maximum of 10. The group of senior interventionists attending the course considered the effort worthwhile and that significant benefit had been derived. They proposed the organization of similar courses for the rest of the members of the society and the promotion of ongoing training. They also proposed the inclusion of refresher courses at future national meetings [44].

Conclusions

Although biomedical physics (BMP) academics are required to provide a contribution to the education of healthcare professionals (HCP) in the majority of Faculties of Medicine/Health Science (FMHS) in Europe, the literature indicates that their precise role has not been appropriately defined nor studied in a systematic manner; no mission statement has been found in the literature which would provide focus, no role development model to help practitioners in pushing their role forward, no curriculum development model to guide teaching. Although there are indications of increasing interest [45–49], the absence of a prominent systematic body of research is a significant handicap and may lead to curricula which do not address the actual present and future learning needs of the modern HCP. The role also seems to have too narrow a scope as it is mostly confined to the education of those HCP linked directly to the traditional historical areas of medical physics (the various imaging modalities, therapeutic radiology and radiation protection) — although there are some signs of role expansion to other HCP such as physiotherapists and nurses [50–53]. The Special Interest Group, therefore, as a first priority will address the following specific research objectives:

- To carry out a Europe-wide position audit for the BMP educator role. The objective of the position audit will be to identify the present strengths and weaknesses of the role and the opportunities and threats to the role arising from changes in the political, economic, sociological and technological—scientific environment and to recognize the curricular challenges arising from developments in higher education in general and HCP education in particular.
- To propose a strategic role development model for the perusal of role holders based on the results of the position audit (including the conceptualization of an updated role mission statement) which would provide a base for the future well-being of the role and its relevance to modern HCP education.
- To propose a curriculum development model for the perusal of role holders which would be based on the role development model and which would be structured enough to permit systematic curriculum development yet be generic enough to be applicable to all HCP and flexible enough to be modifiable according to national and local needs.

References

[8] ESEM (European Society for Engineering and Medicine). The goals and mission of ESEM. Available at: <http://www.esem.org>; 2006 [accessed 20.03.06].
[32] Dendy PP. Syllabus for a course in diagnostic imaging – physical and biological aspects for doctors undergoing specialist training in radiology. Available at: <http://www.efomp.org/docs/ear_syll_rad.htm> [accessed 08.04.05].
[40] Dennis M, Rzeszotarski M, Hendee WR. Point—Counterpoint: to prepare radiology residents properly for the future, their physics education should be expanded in breadth and depth, and should be more quantitative and mathematically-based. Med Phys 2003;30:1956–7.